Smoke Plume Trajectory over Two-Dimensional Terrain

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Under the sponsorship of the US Minerals Management Service and the Alaska Department of Environmental Conservation, the National Institute of Standards and Technology has conducted a series of large outdoor burns of crude oil on water to assess the feasibility of using *in situ* burning as an oil spill remediation tool. In conjunction with these experiments, a numerical (ALOFT - A Large Outdoor Fire plume Trajectory) model has been developed to predict the downwind concentration of smoke particulate and other combustion products.[1] The numerical model has been carefully compared with results from field experiments, and the results are very favorable.[2]

The range of validity of the original model was from a few fire bed diameters downwind to roughly 20 kilometers downwind of the burn, and it was limited to flat terrain. The model has now been extended to cover the burning region and to include terrain effects to the far field. The burn region is resolved with a modified version of the authors' compartment fire model[3] which is a low Mach number, high resolution Navier-Stokes solver. The results of the burn region simulation are used to initialize the windblown model which predicts the rise and dispersion of the particulate matter over distances up to 20 km downwind.

Terrain effects are accounted for by computing the steady, inviscid flow over isolated two-dimensional obstacles in a stratified atmosphere. The formulation allows for a cross-wind that is determined by initial (upstream) conditions and the two-dimensional stratified flow field. Large circulation regions, known as rotors, can form above and in the lee of these ridges. Particulate tends to flow between the rotor and the terrain, dispersing in the lee of the obstacle. Three-dimensional terrain can be handled by a different, three-dimensional, time dependent finite difference model for a Boussinesq, stratified fluid. The downwind domain can be extended until the point is reached where enough dispersion has occurred so that there is no longer a significant health threat.

The ALOFT model has also been extended to accommodate multiple plumes. In the accompanying figure, 3 plumes with flow rates varying from 2.2 to 2.6 kg/s and heat release rates varying from 500 to 700 MW are convected in the first domain by a 6 m/s wind. The total flow rate is 7.2 kg/s and the net heat release rate is 1.8 GW. The atmosphere is linearly stratified at -5°C/km. 10,000 Lagrangian particles are used to track the particulate's path through the plumes. The two grayscale values shown are for 50 and 150 $\mu g/m^3$. Once the complex plume merging dynamics have subsided such that the plume's trajectory is governed by atmospheric forces (5 km in the example), the two-dimensional terrain model can be applied. For this example, the atmosphere contains two crosswind shear periods with extrema of -4 and 4 m/s. The initial crosswind is zero at the ground and above 3 km. The terrain is a 350 m high, bell-curve-shaped peak centered 2.5 km into the second domain with a base width of 3 km. The stronger wind fluctuations found over land disperse the plume more than out at sea. The crosswind further separates the particulate. The multiple plumes have a wider initial angle of separation than a single plume with a flow rae of 7.2 kg/s and a heat release rate of 1.8 GW. Efforts are underway to allow the 2-D terrain model to handle semi-infinite ridges, such as cliffs, which are characteristic of many seashores.

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1. Baum, H.R., McGrattan, K.B., and Rehm, R.G., "Simulation of Smoke Plumes from Large Pool Fires" in *Twenty-fifth International Symposium on Combustion*, 1463 - 1469, 1995.
2. McGrattan, K.B., et al., "Smoke Trajectory from *In Situ* Burning of Crude Oil in Alaska: Field Experiments," NIST Internal Report No. NISTIR 5764, US Dept. of Commerce, Washington, DC, Nov., 1994.
3. Baum, H.R., McGrattan, K.B., and Rehm, R.G., "Large Eddy Simulations of Smoke Movements in Three Dimensions" in *Interflam '96*, 189 - 198, 1996.

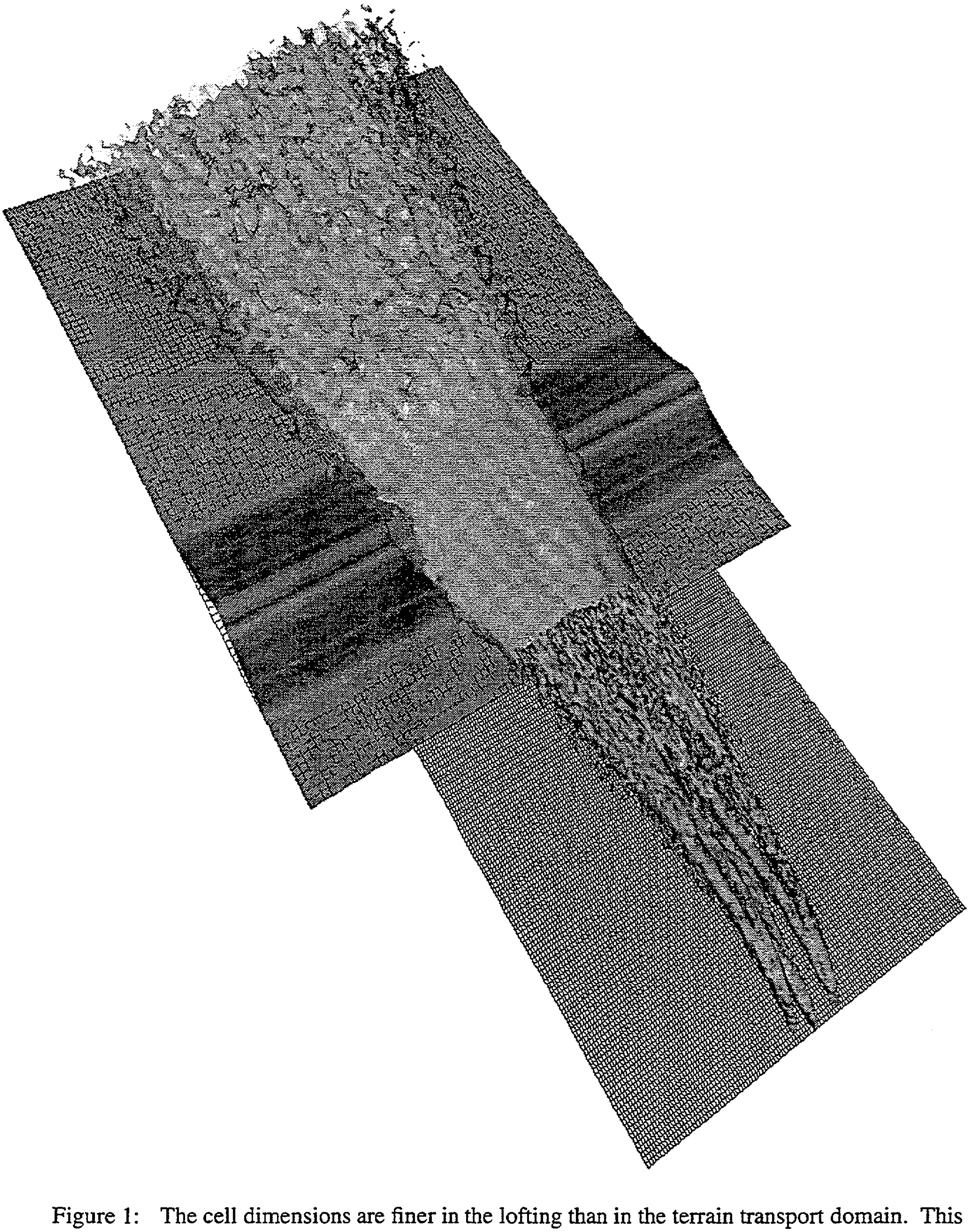

Figure 1: The cell dimensions are finer in the lofting than in the terrain transport domain. This resolution difference accounts for the change in isosurface appearance between the two regions.